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Frattini et al.

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(54) **LED MATRIX MANAGER**

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Related U.S. Application Data

(60) Provisional application No. 61/591,220, filed on Jan. 26, 2012, provisional application No. 61/593,624, filed on Feb. 1, 2012, provisional application No. 61/591,223, filed on Jan. 26, 2012, provisional application No. 61/591,215, filed on Jan. 26, 2012, provisional application No. 61/591,226, filed on Jan. 26, 2012.

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G09G 5/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H05B 37/036*** (2013.01); ***H05B 33/083*** (2013.01); ***H05B 33/0842*** (2013.01); ***H05B 37/02*** (2013.01)

(58) **Field of Classification Search**
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USPC .... 315/276, 277, 279, 280, 282, 283, 284, 315/291, 307, 200 R, 209 R; 363/122, 125, 363/126, 130, 136
See application file for complete search history.

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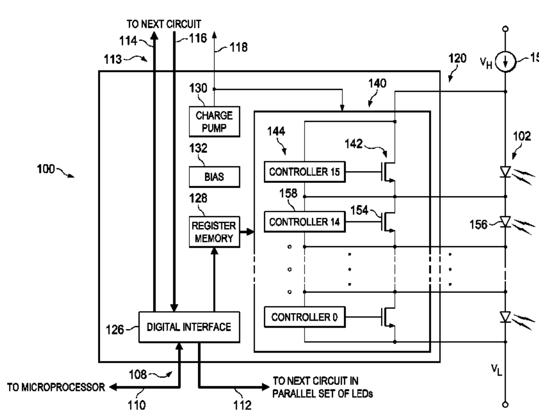
(57) **ABSTRACT**

Circuits for controlling a plurality of LEDs connected in series are disclosed herein. The circuit includes a plurality of switches, wherein each switch is connectable between the anode and cathode of one of the plurality of LEDs. Each of the switches has a first state wherein current does not pass through the switch and a second state wherein current passes through the switch. The circuit also includes an input for receiving data to program the switches and a data line for transferring data between a circuit controlling second LEDs that are connected in parallel with the first LEDs and the circuit. In addition, the circuit includes a data output for transferring data to other circuits controlling third LEDs that are connected in series with the first LEDs.

22 Claims, 8 Drawing Sheets



(51) **Int. Cl.**

H05B 37/03	(2006.01)
H05B 37/02	(2006.01)
H05B 33/08	(2006.01)

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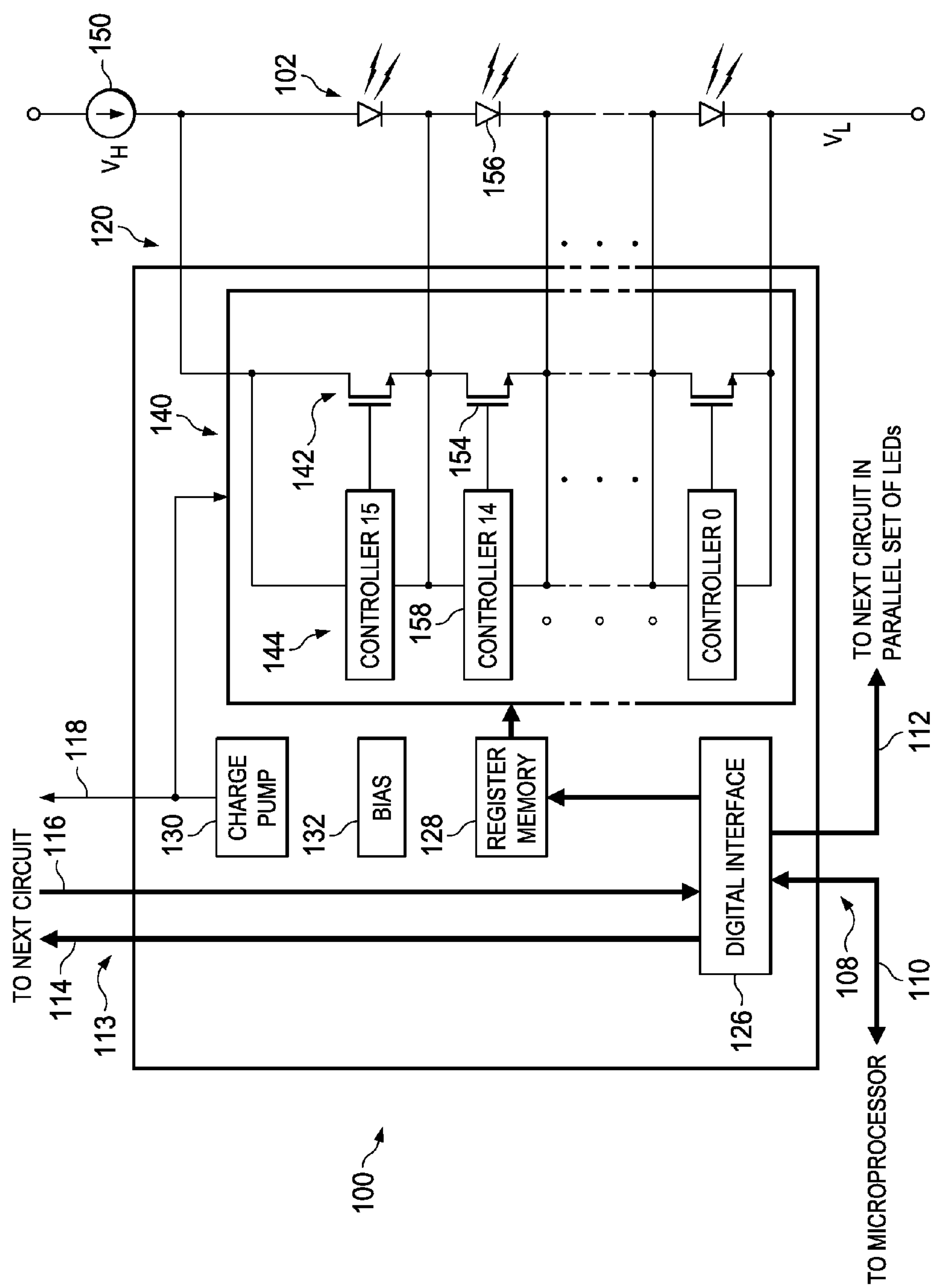
100
102
108
110
112
113
114
116
118
120
126
128
130
132
140
142
144
150
154
156
158
V_H
V_L
CONTROLLER 15
CONTROLLER 14
CONTROLLER 0
CHARGE PUMP
BIAS
REGISTER MEMORY
DIGITAL INTERFACE
TO NEXT CIRCUIT
TO MICROPROCESSOR
TO NEXT CIRCUIT IN PARALLEL SET OF LEDs

FIG. 1

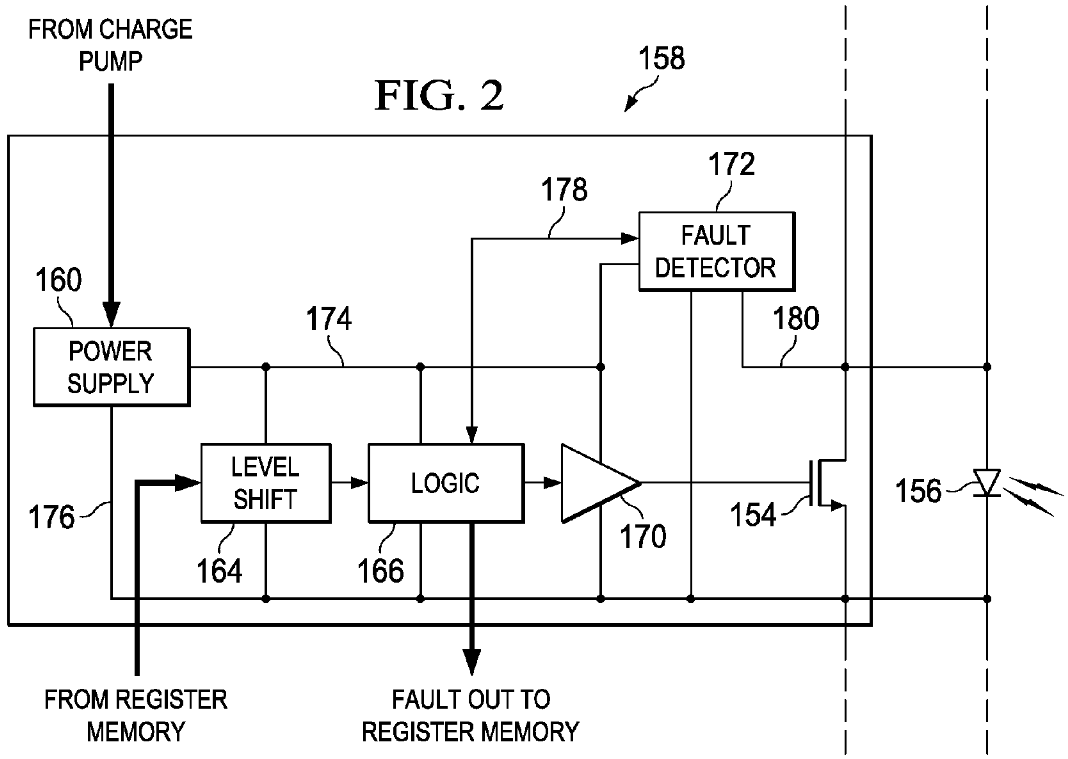
FROM CHARGE PUMP
158
160
POWER SUPPLY
174
178
172
FAULT DETECTOR
180
LEVEL SHIFT
LOGIC
176
164
166
170
154
156
FROM REGISTER MEMORY
FAULT OUT TO REGISTER MEMORY

FIG. 2

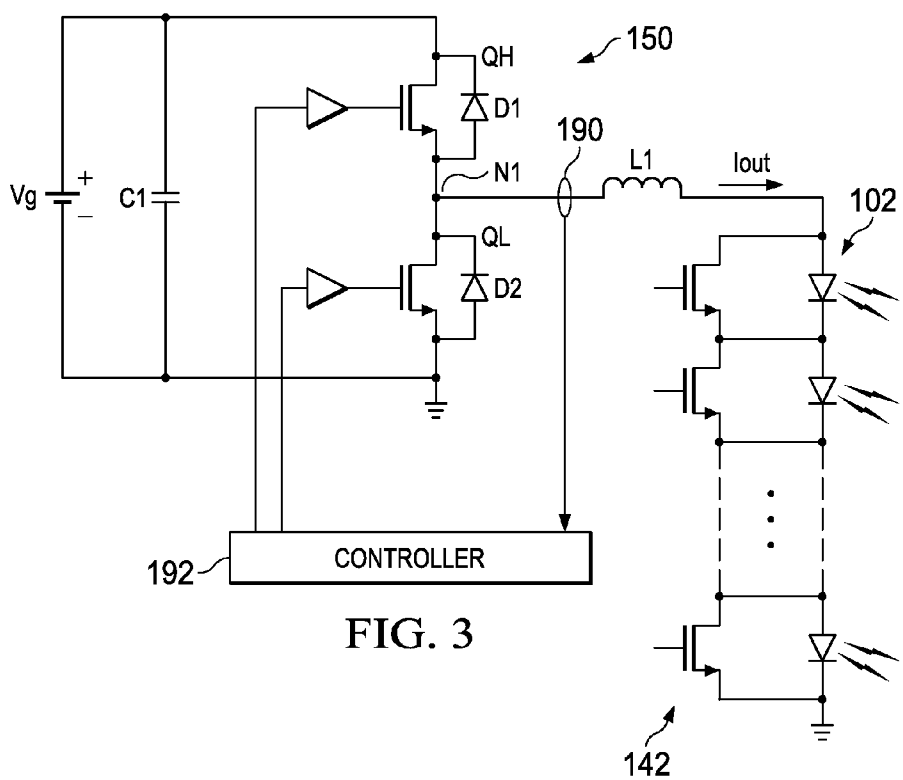
150
QH
D1
N1
190
L1
Iout
102
Vg
C1
QL
D2
CONTROLLER
192
142

FIG. 3

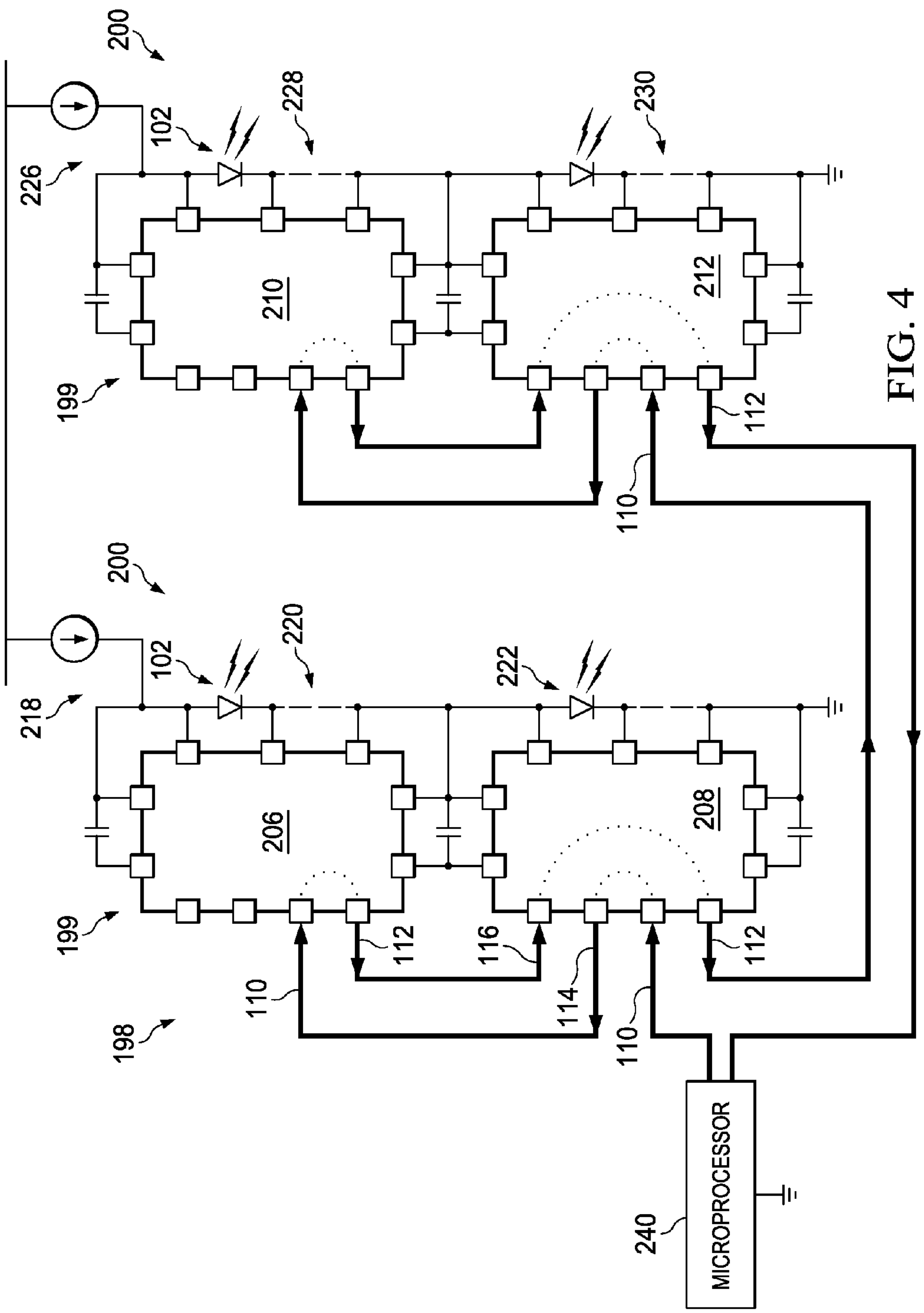
200
228
230
102
226
210
212
199
112
110
200
220
222
102
218
206
208
199
112
116
114
110
112
198
110
240
MICROPROCESSOR

FIG. 4

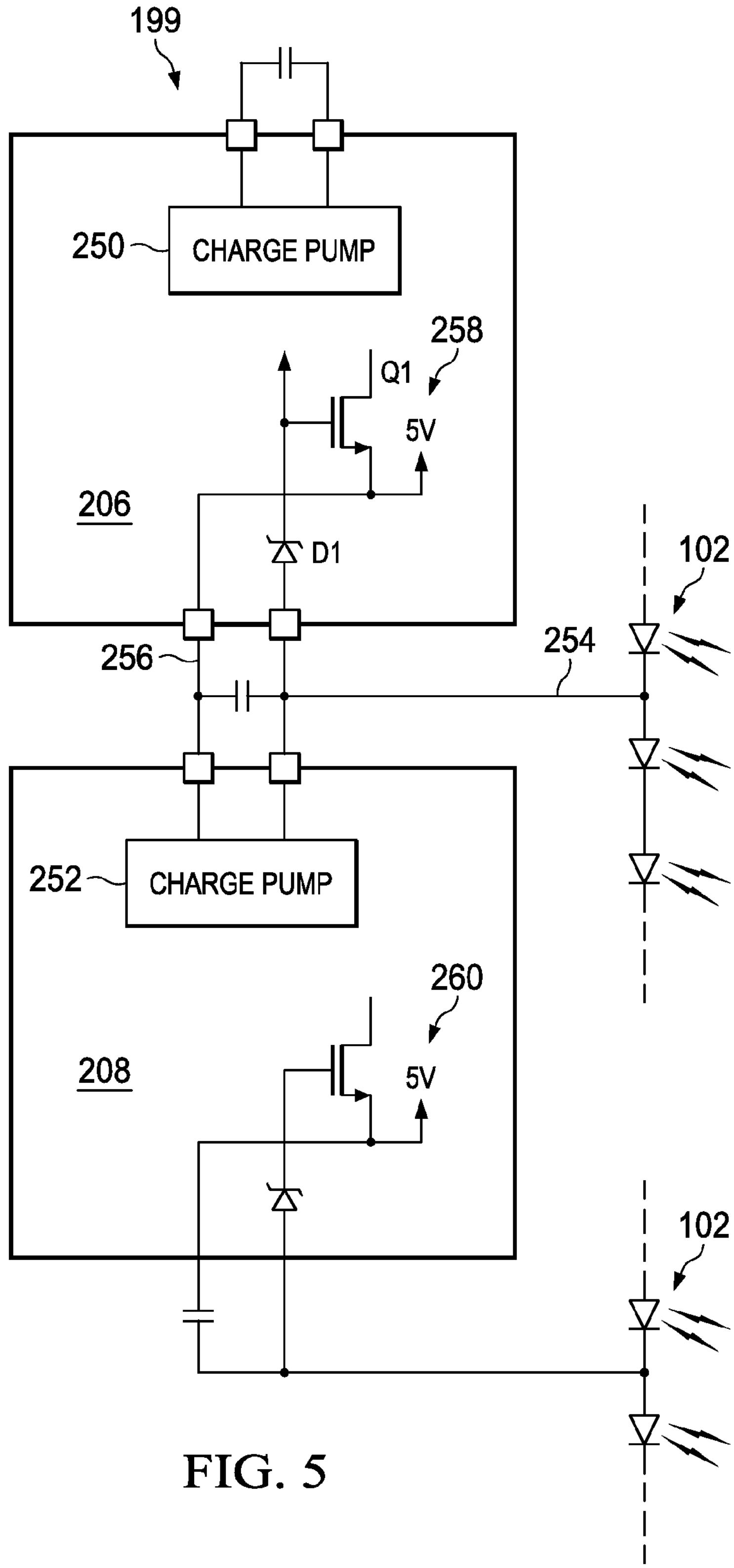
199
250
CHARGE PUMP
258
Q1
5V
206
D1
102
254
256
252
CHARGE PUMP
260
208
5V
102

FIG. 5

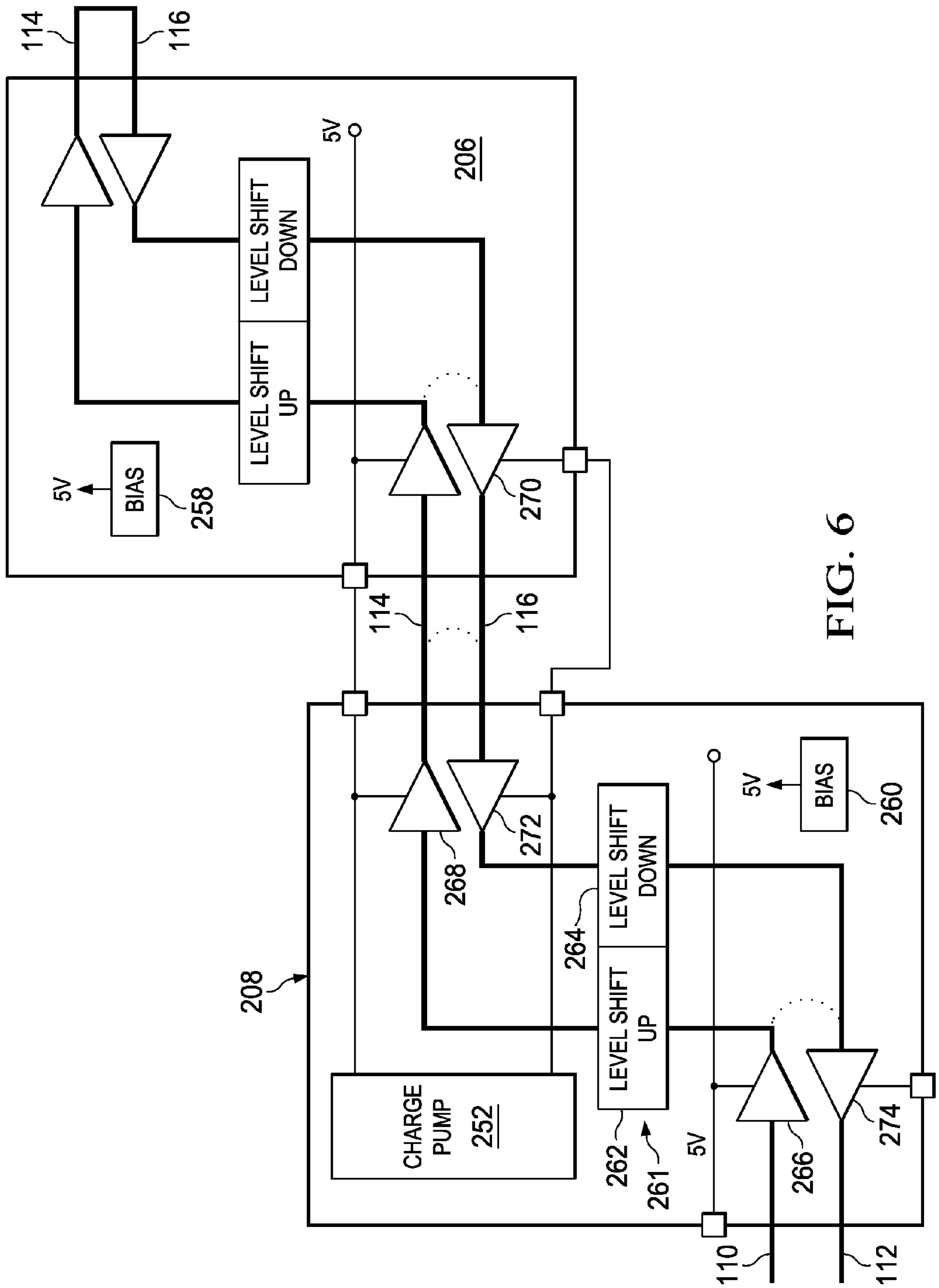
114
116
5V
206
LEVEL SHIFT DOWN
LEVEL SHIFT UP
BIAS
258
270
114
116
208
268
272
264
LEVEL SHIFT DOWN
LEVEL SHIFT UP
CHARGE PUMP 252
262
261
5V
266
274
BIAS
260
110
112

FIG. 6

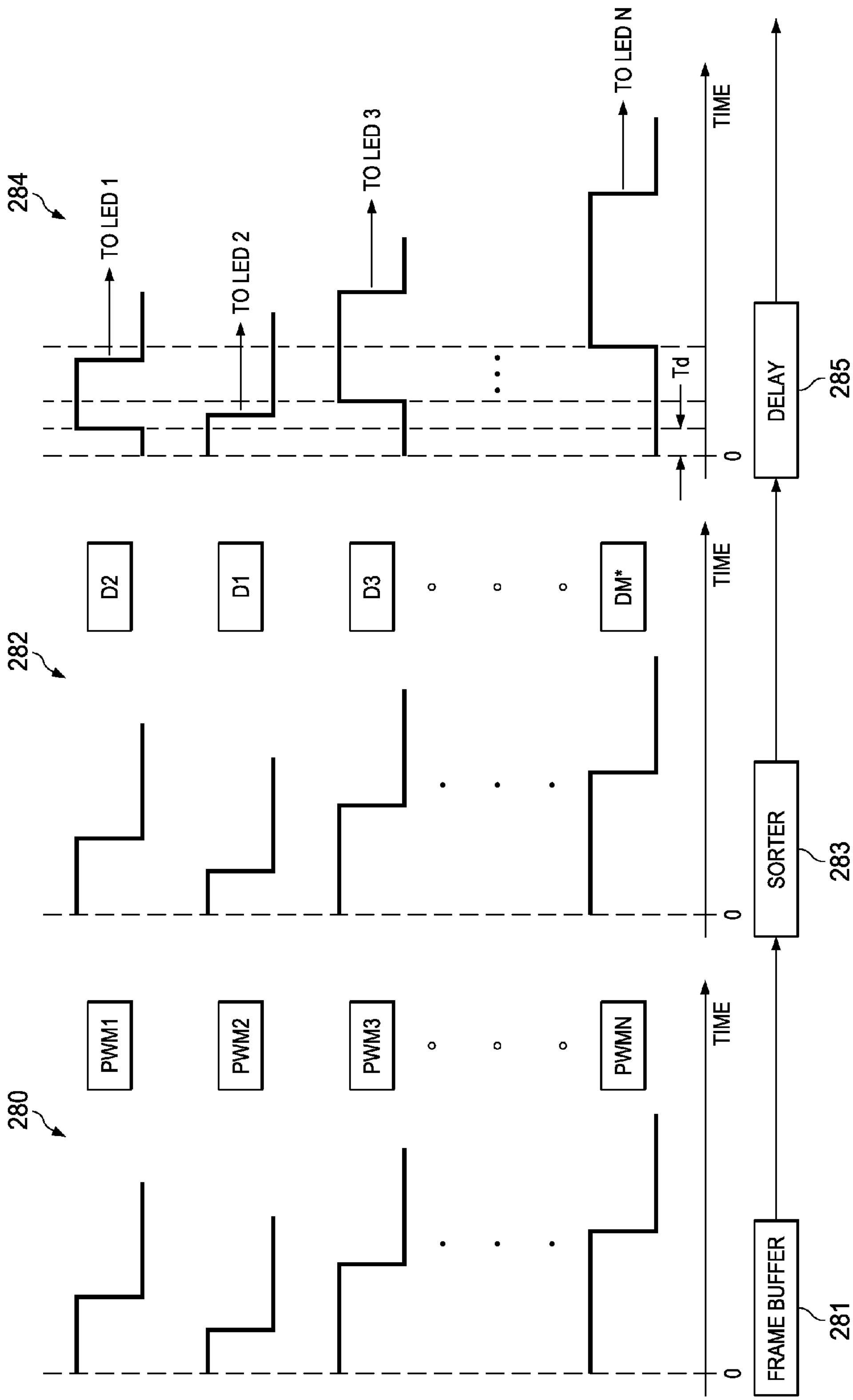
284
TO LED 1
TO LED 2
TO LED 3
TO LED N
TIME
Td
0
282
D2
D1
D3
DM*
TIME
0
280
PWM1
PWM2
PWM3
PWMN
TIME
0
FRAME BUFFER
281
SORTER
283
DELAY
285

FIG. 7

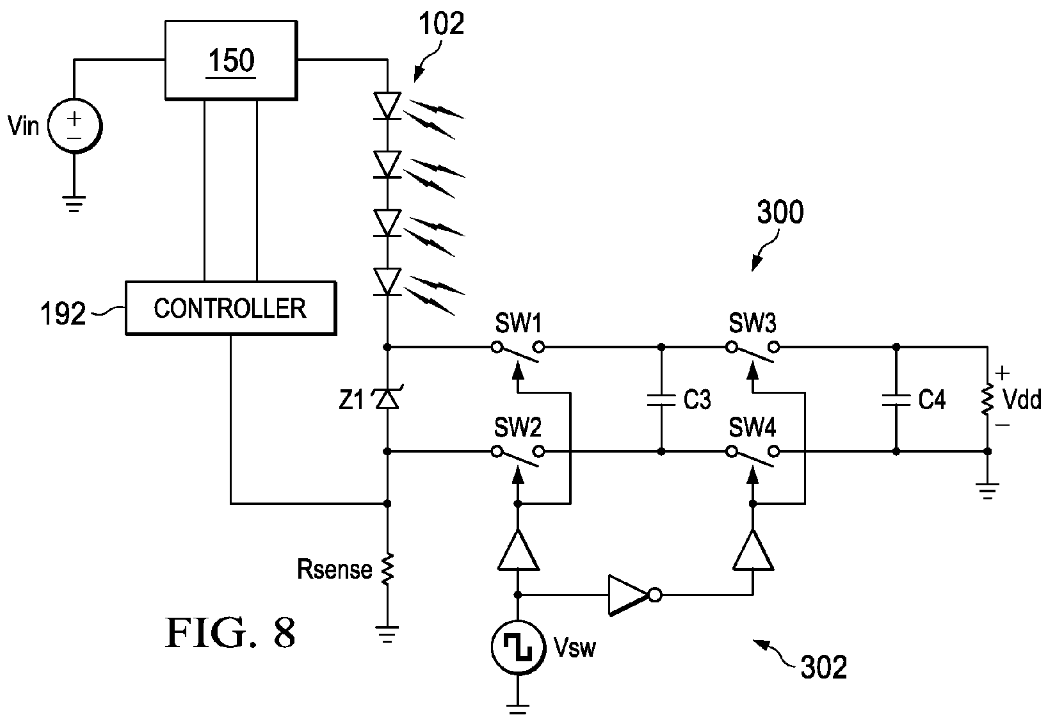
102
150
Vin
300
192
CONTROLLER
SW1
SW3
Z1
C3
C4
Vdd
SW2
SW4
Rsense
Vsw
302

FIG. 8

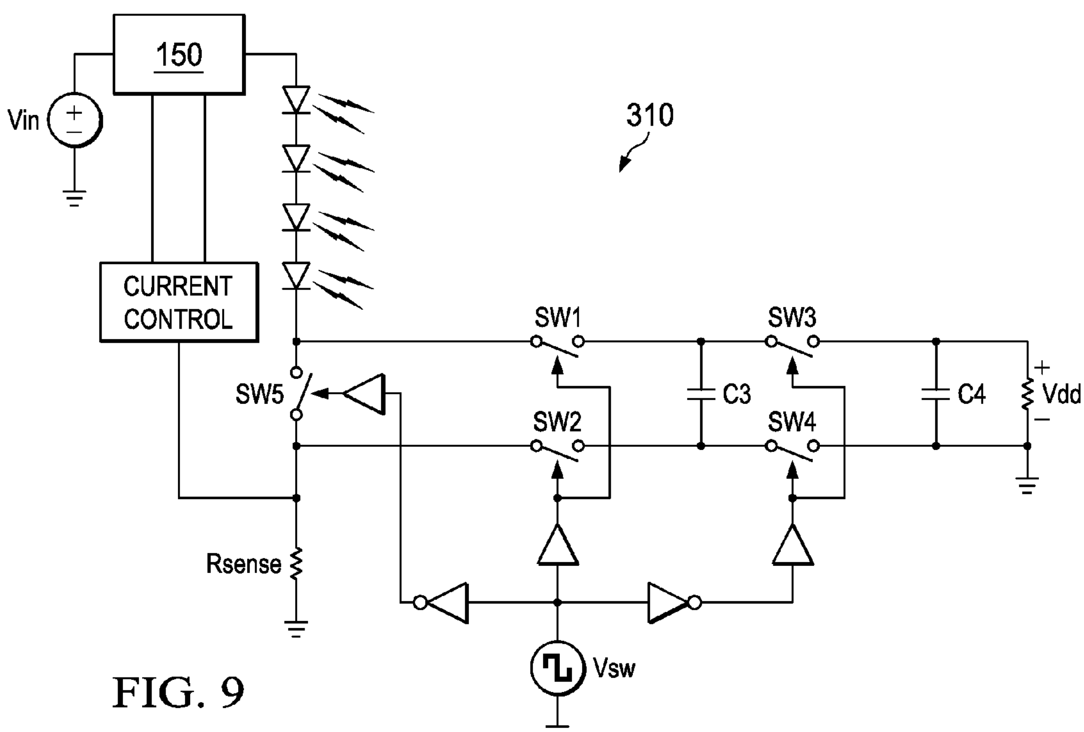
150
Vin
310
CURRENT
CONTROL
SW1
SW3
SW5
C3
C4
Vdd
SW2
SW4
Rsense
Vsw

FIG. 9

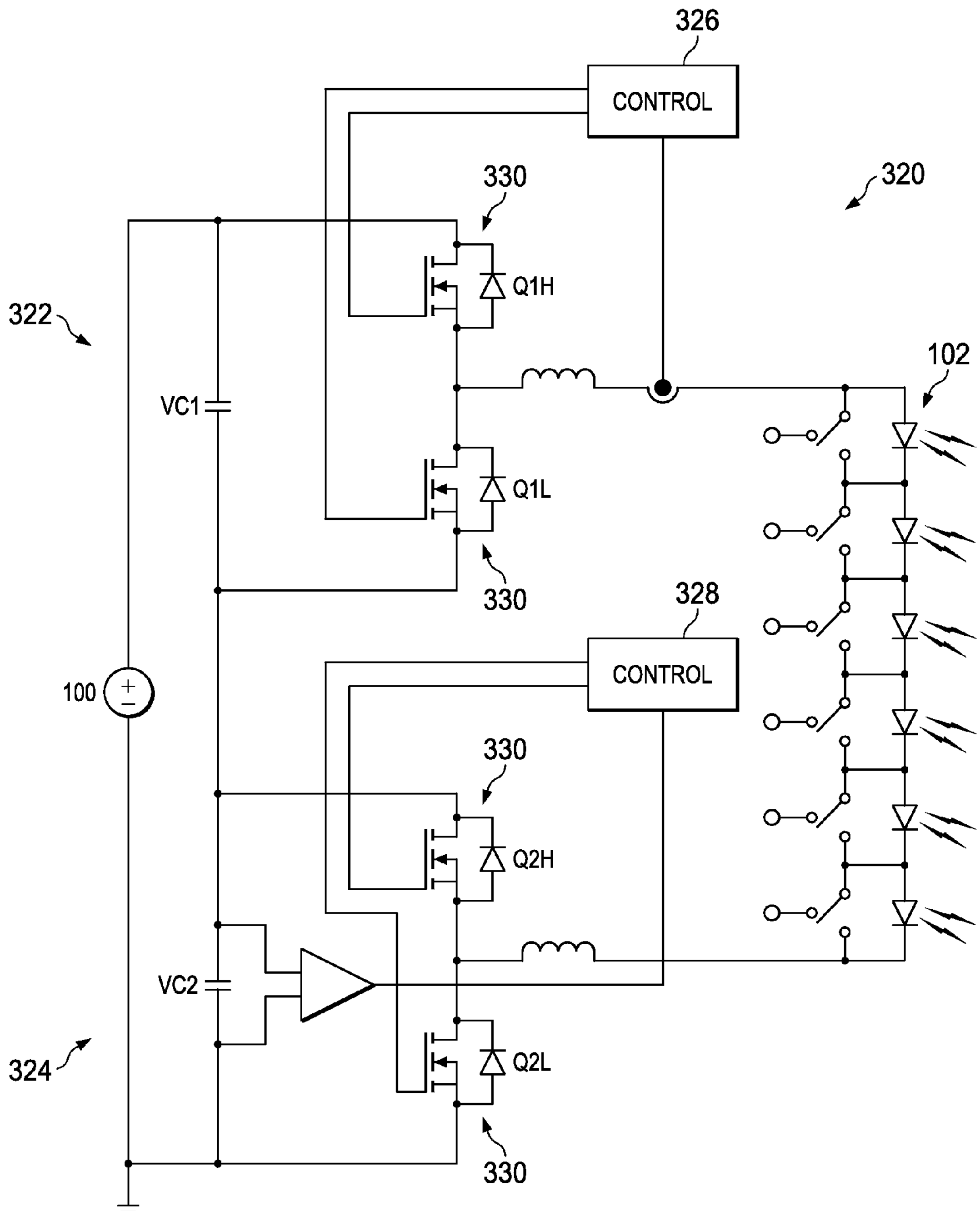
326
CONTROL
330
320
Q1H
322
102
VC1
Q1L
330
328
CONTROL
100
330
Q2H
VC2
Q2L
324
330

FIG. 10

LED MATRIX MANAGER

This application claims priority from the following United States Provisional patent applications:

U.S. provisional patent application 61/591,220 filed on Jan. 26, 2012 for METHOD OF CONNECTING TWO BUCK CURRENT REGULATORS IN SERIES WHILE INSURING INPUT VOLTAGE BALANCING;

U.S. provisional patent application 61/593,624 filed on Feb. 1, 2012 for LED MATRIX MANAGER;

U.S. provisional patent application 61,591,223 filed on Jan. 26, 2012 for OPTIMAL STAGGERING CONTROL OF DIMMABLE LED ARRAYS;

U.S. provisional patent application 61/591,215 filed on Jan. 26, 2012 for ULTRA FAST-RESPONSE CURRENT SOURCE FOR STRINGS OF INDIVIDUAL DIMMAGLE LEDS IN SERIES; and

U.S. provisional patent application 61/591,226 filed on Jan. 26, 2012 for LOW-COST BIAS VOLTAGE GENERATION CIRCUIT FOR HIGH-VOLTAGE CURRENT REGULATORS.

BACKGROUND

Many lighting applications are moving from conventional light sources to light-emitting diode (LED) sources. One area where LEDs are used is in display boards where the LEDs are arranged in strings wherein the LEDs are connected in series. One problem with arranging LEDs in strings is that all the LEDs in the string are managed together. For example, all the LEDs are turned off and on, and thus dimmed, together. The LEDs are not controlled individually. In addition, if one LED becomes dysfunctional with an open circuit, the entire string of LEDs may become dysfunctional and there is no way for a controller to resolve the problem.

SUMMARY

Circuits for controlling a plurality of LEDs connected in series are disclosed herein. The circuit includes a plurality of switches, wherein each switch is connectable between the anode and cathode of one of the plurality of LEDs. Each of the switches has a first state wherein current does not pass through the switch and a second state wherein current passes through the switch. The circuit also includes an input for receiving data to program the switches and a data line for transferring data between a circuit controlling second LEDs that are connected in parallel with the first LEDs and the circuit. In addition, the circuit includes a data output for transferring data to other circuits controlling third LEDs that are connected in series with the first LEDs.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an embodiment of a circuit for controlling a plurality of LEDs.

FIG. **2** is a schematic diagram of a controller of the circuit of FIG. **1**.

FIG. **3** is a schematic diagram of an embodiment of the current source of FIG. **1**.

FIG. **4** is a block diagram of a plurality of circuits connected together to operate an array of LEDs.

FIG. **5** is a schematic diagram of the power supply configuration between the circuits of FIG. **4**.

FIG. **6** is a schematic diagram of the data transmission between the circuits of FIG. **5**.

FIG. **7** is an example of a timing diagram showing pulse width modulated drive signals for the LEDs of FIG. **1**.

FIG. **8** is an embodiment of a circuit for converting the current supplying the LEDs of FIG. **1** to a low voltage source.

FIG. **9** is another embodiment of a circuit for converting the current supplying the LEDs of FIG. **1** to a low voltage source.

FIG. **10** is an embodiment of series current regulators that balance their input voltage.

DETAILED DESCRIPTION

Circuits for controlling a plurality of LEDs are disclosed herein. A block diagram of an embodiment of a circuit **100** is shown in FIG. **1**. The circuit **100** drives a plurality of LEDs **102**, wherein the LEDs **102** are connected in series so that the cathode of one LED is connected to the anode of another LED. The circuit **100** has several ports for transmitting and/or receiving digital or binary data signals. A first port **108** has an input **110** that is connectable to a microprocessor or other circuit (not shown in FIG. **1**). The microprocessor sends data to the circuit **100** regarding the operation of the LEDs **102**. The first port **108** also has a line **112** that is connectable to another circuit that is identical or substantially identical to the circuit **100**. This other circuit may control a different plurality of LEDs as described in greater detail below. A second port **113** has an output **114** and an input **116** that are connectable to another circuit (not shown in FIG. **1**) that controls LEDs that may be connected in series with the LEDs **102**. The circuit **100** also has a power connection **118** that is connectable to another circuit (not shown in FIG. **1**) or a power source.

The circuit **100** has a plurality of terminals **120** that are connectable to the LEDs **102**. Each terminal **120** is connectable to an anode or cathode of one of the LEDs **102**. Therefore, there is one more terminal **120** than the number of LEDs **102**. For example, if the circuit **100** is capable of controlling sixteen LEDs **102**, there must be seventeen terminals **120**. As described below, the terminals **120** provide bypass circuits for each of the LEDs **102** so that the terminals **120** provide mechanisms for turning each of the LEDs **102** on and off.

The circuit **100** includes several internal circuits that perform a variety of functions. A digital interface **126** receives and transmits data to and from the microprocessor and other circuits by way of the first port **108** and the second port **113**. The digital interface **126** receives data from the input **110**, which is connectable to another circuit or a microprocessor. The digital interface **126** may perform initial analysis of the data to determine where the data should be transmitted. In some situations, the data is transmitted to another circuit by way of the line **112** or the output **114**. The digital interface **126** may also receive data from the other circuit by way of the input **116**. It is noted that in some embodiments, first port **108** may process two-way data. Accordingly, the line **112** may receive data from other circuits and pass the data to the microprocessor by way of the input **110**.

As briefly described above, the data received by the circuit **100** may be intended for the circuit **100**, in which case it may be transferred to a register memory **128**. The register memory **128** decodes and/or stores the data so that it can ultimately be used to operate the LEDs **102**. The data may contain information to individually control the LEDs **102**. For example, the data may contain information as to how long each of the LEDs **102** is to remain on or off, which enables pulse width modulation (PWM) to control the brightness of each of the LEDs **102**.

A charge pump **130** provides the correct voltage to operate the circuit **100** from the voltage used to operate the LEDs **102**. As described below, the use of the charge pump **130** enables the circuit **100** to operate from the relatively high voltage that is used to drive the LEDs **102**. The charge pump **130** may also supply power to another circuit (not shown in FIG. **1**) so that the other circuit does not need to be connected to a separate power supply. A bias circuit **132** may receive power from the charge pump **130** so as to provide the operating voltage for the different components within the circuit **100**.

A switching circuit **140** receives data from the register memory **128** and power from the charge pump **130** or bias **132** to operate the LEDs **102**. In a simple form shown in FIG. **1**, the switching circuit **140** has a plurality of switches **142** that are connectable between the anodes and cathodes of each of the LEDs **102**. The switches **142** depicted herein are FETs, but other forms of switches could be used in the circuit **100**. The switches **142** are controlled by controllers **144**, wherein each switch is connected to a controller.

Having described the components of the circuit **100**, the operation of the circuit **100** will now be described. More detailed embodiments of the components within the circuit **100** and descriptions of their operations are described further below.

Data from a microprocessor or controller (not shown in FIG. **1**) is received at the input **110** and is transmitted to the digital interface **126**. The digital interface **126** determines where the data should be transmitted. For this description, it is assumed that the data received is meant to control the LEDs **102** that are connected to the terminals **120** of the circuit **100**. The data includes information as to which of the LEDs **102** is to be illuminated and the brightness of each of the LEDs **102**. This information is stored and/or decoded by the register memory **128**.

A current source **150** drives the LEDs **102**, which causes them to illuminate. All of the switches **142** may be normally open, so current normally passes through all of the LEDs **102**, which puts them in a state where they are normally on. The data in the register memory **128** instructs the controllers **144** to open or close individual switches **142**. Open switches **142** will turn on their associated LEDs **102** and closed switches **142** will turn off their associated LEDs **102**. Reference is made to an individual switch **154** and its associated individual LED **156** and controller **158**. As shown in the circuit **100**, when the switch **154** is open, the LED **156** has current from the current source **150** passing through it and it illuminates. By closing the switch **154**, the current bypasses the LED **156**, which turns the LED **156** off. By turning the switch **154** on and off, such as by using PWM, the brightness of the LED **156** can be controlled. The current source **150** has been shown as being connected to the top of the string of LEDs **102**, which is the anode end of the string. However, the current source **130** could also be connected to the bottom of the string of LEDs **102**, which is closest to the cathode end of the string.

A more detailed embodiment of the controller **158** is shown in FIG. **2**. The controller **158** controls the switch **154**, which controls the LED **156**. The controller **158** is representative of all the controllers **144** in the circuit **100**, FIG. **1**. The controller **158** may include a local power supply **160** that may be connected to the charge pump **130**, FIG. **1**. The power supply **160** regulates the voltage received from the charge pump **130** so that it can operate the components within the controller **158**. The power supply **160** may also reference the voltage to a common ground potential used by the controller **158**. Due to the use of the charge pump **130**, FIG. **1**, the ground potentials of different circuits may vary, so a common ground is used with respect to the controller **158**. The power supply is referenced to the cathode of the LED **156** in order for the switch **154** to be able to turn it off and on. As described below, the charge pump **130** generates a voltage that is high enough for the controller **158** to operate the switch **154**, wherein this voltage may be higher than the voltages required to operate other components of the circuit **100**.

A level shift circuit **164** (sometimes referred to herein simply as a "level shift **164**") receives data from the registry memory **128**, FIG. **1**. The data contains information as to how bright the LED **156** should illuminate. In some embodiments, the register memory **156** transmits a PWM signal to the level shift **164**. In other embodiments, the register memory **128** transmits a value to the level shift **164** indicating the brightness of the LED **156**. The level shift **164** may then generate a drive signal for the LED **156**, which may be a PWM signal.

The level shift **164** may convert the received data signal to voltages that can be used by the controller **158**. As described in greater detail below, the circuit **100**, FIG. **1**, may operate at a different voltage than other circuits (not shown in FIG. **1**) that are connected to the circuit **100**. For example, the ground of one circuit may be at a different potential than the ground of another circuit. Likewise the controllers **144**, FIG. **1**, may all operate at different voltage potentials. This may cause the data signals to be at different voltage potentials. The level shift **164** converts the data signals to voltage potentials that operate within the controller **158**.

The level shift **164** is connected to a logic circuit **166**. The logic circuit **166**, among other things, tests the functionality of the LED **156** and determines whether the switch **154** should be open or closed based on the functionality. The logic circuit **166** may also transmit data to the register memory **128** as to the status of the LED **156**. The logic circuit **166** drives a driver **170**, which may be an amplifier or buffer that drives the gate of the switch **154**. A fault detector **172** tests the LED **156** to determine if it is functional. If the LED **156** is not functional, a signal is transmitted to the logic circuit **166** to cause the switch **154** to remain closed.

The operation of the controller **158** will now be described. Power is supplied to the power supply **160** from the charge pump **130**, FIG. **1**. The power supply **160** outputs a regulated voltage on a line **174** that is referenced relative to a common voltage on a line **176**. The voltage on the line **174** powers the components within the controller **158** and is high enough to turn the switch **154** on. In order to operate the switch **154**, a voltage must be applied to the gate terminal that is higher than the voltage on the other two terminals, drain and source, connected to the LED **154**. Because the LED **154** could be the top of the string of LEDs **102**, its anode can be connected directly to the current source **150**. The charge pump **130** generates a voltage higher than the voltage on the anode in order to ensure that the power supply **160** can generate a voltage for the driver **170** that can keep the gate of the switch **154** at a voltage that is higher than the voltage on the anode even when the switch **154** is on.

The fault detector **172** tests the LED **156**. The logic circuit **166** may receive instructions to cause the fault detector **172** to test the LED **156**. The test on the LED **154** involves the fault detector **172** sending a signal to the logic circuit **166** via the line **178** that causes the switch **154** to open. The LED

156 should illuminate and have a forward voltage drop between its anode and cathode. This forward voltage drop is measured by a line 180 relative to the common line 176. If the forward voltage is correct, the LED 156 is operating correctly. If the forward voltage is zero, then the LED 156 is shorted. If the forward voltage is greater than the forward operating voltage of the LED 156 then the LED 156 is open. If the LED is not operating correctly, the fault detector 172 sends a signal to the logic circuit 166 that causes the switch 154 to remain closed, which bypasses the LED 156. If the LED 156 is open, bypassing the LED 156 will not cause the other LEDs 102, FIG. 1, connected in series with the LED 156 to fail to illuminate.

If the fault detector 172 determines that the LED 156 is operating properly, it sends a signal to the logic circuit 166 by way of the line 178 that enables the logic circuit 166 to control the illumination of the LED 156. During normal operation, a data value may be received by the level shift 164 from the register memory 128, FIG. 1, wherein the data value is indicative of the brightness required for the LED 156. The level shift 164 may convert the data to pulses in the form of a (PWM) signal, wherein the longer pulses cause the LED 156 to illuminate for greater periods, which makes the LED 156 appear brighter.

The signals from the level shift 164 are transmitted to the logic circuit 166. Because the fault detector 172 determined that the LED 156 is operating properly, the logic circuit 166 passes the signals to the driver 170. The driver 170 drives the gate of the switch 154. When the switch is open, the LED 156 illuminates. Therefore, the driver 170, or other components in the circuit 100, may invert the (PWM) signal so that the logic high pulses open the switch 154 and cause the LED 170 to illuminate.

Referring again to FIG. 1, each of the controllers 144 may operate in the same manner as the controller 158 described in FIG. 2. Accordingly, each of the LEDs 102 connected to the circuit 100 may be controlled individually. For example, data may be received by the digital interface 126 and transmitted to the register memory 128. Based on the data, the register memory 128 may output data to the individual controllers 144 to indicate the amount of time that their corresponding LEDs 102 are to be illuminated.

As shown in FIG. 1, the LEDs 102 are driven by a current source 150. The current source 150 needs to provide a constant current irrespective of the cumulative voltage build up on the LEDs 102. For example, if all the LEDs 102 are illuminating, the voltage on the string of LEDs 102 will be the sum of the individual forward voltages of all the LEDs 102. As individual LEDs 102 are turned off, the cumulative voltage decreases, however, the current through the LEDs 102 must remain constant or the illumination of the LEDs 102 will change.

A detailed schematic of an embodiment of the current source 150 is shown in FIG. 3, wherein the current source 150 is a constant current source. The current source 150 includes a DC voltage supply Vg, sometimes referred to simply as the supply Vg. The voltage supply Vg is referenced to ground, which may be the same potential as the end of the string of LEDs 102. For reference, the voltage supply Vg has a positive line and a negative line, wherein the negative line is connected to ground.

A capacitor C1 is connected between the positive line and the negative line of the voltage supply Vg. A first switch QH is connected between the positive line and a node N1. A second switch QL is connected between the node N1 and the negative line. In the embodiment of FIG. 3, the switches QH, QL are FETs wherein the drain of QH is connected to the positive line and the source of QL is connected to the negative line. A diode D1 is connected between the source and drain of QH and a diode D2 is connected between the source and drain of QL. The diodes D1, D2 attenuate transients that may occur across QH and QL.

The node N1 is connected to an inductor L1, which is connected to the LEDs 102. Therefore, the current required to operate the LEDs 102 flows through the inductor L1. It is noted that there are no capacitors connected across or in parallel with the string of LEDs 102. A current sensor 190 measures the current flow through the inductor L1, and thus, through the LEDs 102. The current sensor 190 and the gates of QH and QL are connected to a controller 192, which turns the switches QH and QL off and on.

The controller 192 turns the switches QH and QL off and on to regulate the current that passes through the inductor L1. The current sensor 190 measures the current flow through the inductor L1 and outputs data related to the current flow to the controller 192. The controller 192 changes the open and closed times of the switches QH and QL in order to maintain the current necessary to operate the LEDs 102. For example, if more current is required by the LEDs 102, the controller 192 may open QL and close QH for longer periods. The storage properties of the inductor L1 work to maintain a constant current by enabling rapid voltage changes. Therefore, the inductor L1 can absorb voltage changes as a result of the LEDs 102 turning off and on while maintaining a constant current flow through the LEDs 102. As described above, there is no capacitor connected in parallel with the LEDs 102. Therefore, the voltage that appears at the top of the LEDs 102 where current source 150 is connected can change very rapidly.

Having described the operation of the current source 150, the connection between several circuits will now be described. As briefly described above, several circuits 100 may be connected together in order to control an array of LEDs. An example of the circuits 100 connected together to form a device 198 is shown in FIG. 4, which is a schematic illustration of a plurality of circuits 199 connected together to operate an array 200 of LEDs 102. The circuits 199 are identical to the circuit 100, FIG. 1, are referred to individually as the first circuit 206, the second circuit 208, the third circuit 210, and the fourth circuit 212. The first and second circuits 206, 208 operate a first string of LEDs 218, wherein the first circuit 206 operates a first portion of LEDs 220 and the second circuit 208 operates a second portion of LEDs 222. The third and fourth circuits 210, 212 operate a second string of LEDs 226, wherein the third circuit 210 operates a third portion of LEDs 228 and the fourth circuit 212 operates a fourth portion of LEDs 230.

The array 200 is shown with the first string of LEDs 218 and the second string of LEDs 226 connected in parallel. It is noted that the strings of LEDs 218, 226 are in parallel, but they may not necessarily be electrically connected in parallel. Any number of parallel strings of LEDs may be added to the array 200. Likewise the strings of LEDs 218, 226 each only have two portions that are connected in series. The strings of LEDs 218, 226 may be expanded to include any number of portions. The use of a larger array 200 enables the array 200 to display more information by having more LEDs 102 that may be illuminated.

A microprocessor 240 is connected to the data lines that are connected to the circuits 199. The microprocessor 240 transmits data to all the circuits 199 that includes information as to which LEDs 102 are to be illuminated and the period of illumination. For example, the data may include header information that determines which of the circuits 199 is to receive the data, followed by illumination data for each of the LEDs connected to that particular circuit. The microprocessor **240** transmits data to the input **110** of the second circuit **208**. As shown in FIG. **1**, the input **110** is connected to a digital interface **126**, FIG. **1**. If the data received is meant to operate the second portion of LEDs **222** connected to the second circuit **208**, the digital interface **126**, FIG. **1**, will process the data and transmit it to the register memory **128**, FIG. **1**. Otherwise, the digital interface **126** transmits the data to the output **114**, which is connected to the input of the first circuit **206**. As with the second circuit **208**, the digital interface **126** determines if the data is meant to operate the portion of LEDs **220** connected to the first circuit **206**.

The first circuit **206** is located at the top of the first string of LEDs **218**. Therefore, the first circuit **206** will not transmit data to any other circuits associated with the first string of LEDs **218**. The first circuit **206** may detect that there are no circuits connected to the input **116** and the output **114**, or the first circuit **206** may be programmed to function as the top circuit in the string of LEDs **218**. The digital interface **126**, FIG. **1**, will either save the data received on the input **110** or transmit the data to the line **112**. In other embodiments, the output **114**, and the input **116** of the first circuit **206** may be electrically connected to each other. Regardless of the embodiment, the data not meant for the first circuit **206** is transmitted on the line **112** to the next circuit in the first string of LEDs **218**, which is the second circuit **208**.

Data received on the input **116** of the second circuit **208** is passed to the line **112** because the data has already been analyzed and is not meant for the second circuit **208**. More specifically, if the data is received on the input **116**, it has been analyzed by all the circuits in the string of LEDs **218** and is meant to be transmitted to a parallel string of LEDs. The line **112** of the second circuit **208** is connected to the input **110** of the fourth circuit **212**. Therefore, data from the first string of LEDs **218** is transmitted to the second string of LEDs **226** and the above-described process is repeated. The line **112** of the fourth circuit **212** is connected back to the microprocessor **240**. Data on this line may include locations of LEDs that were tested and that are not functioning. The microprocessor **240** may operate to lessen the visual impact of defective LEDs as known in the art.

Having described the data transmissions in the array **200**, the power distribution will now be described. The string of LEDs **102** may have a relatively high voltage between the top LED and the bottom LED. In some embodiments, the voltage is approximately 100 volts. The components within a circuit **100** may operate on five volts. Circuits are disclosed herein that enable the high voltage operating the LEDs **102** to operate the low voltage components in the circuits **100**.

The power may be supplied to the circuits **199** by use of the charge pump **130**, which is connected to the LEDs **102**. An embodiment of the power supply using the charge pump **130** is shown in FIG. **5**, which is a schematic illustration of the first circuit **206** and the second circuit **208** connected together. In order for the circuits **206**, **208** to receive power from the LEDs **102** and to drive the electronic components therein, charge pumps are used. A first charge pump **250** is located in the first circuit **206** and a second charge pump **252** is located in the second circuit **208**. In summary, the charge pumps **250**, **252** generate the proper operating voltage for the circuits **206**, **208** from the voltage present across the LEDs **102**. In the embodiments described herein, the charge pumps **250**, **252** and associated voltage regulators generate the voltages required to operate the electronic components within the circuits **199**.

In order to better describe the charge pumps, additional reference is made to FIGS. **1** and **2** and the charge pump **130**. The charge pump **130** is powered by the string of LEDs **102**. Therefore, the supply voltage for the charge pump is between the highest voltage at the anode at the top of the string of LEDs **102** and the cathode at the bottom of the string. When a switch **142** is on, the drain to source voltage drops. Ideally, the voltage drop is zero, but it may be a few millivolts. The voltage at the top LED that is off will not be high enough to operate its corresponding switch. The charge pump **130** generates this higher voltage to operate the switches **142**.

There will be situations where all the switches **142** are on so that all the LEDs **102** are bypassed and the total voltage across the string of LEDs **102** can be as low as a few hundred millivolts. In this case all the controllers **140** need their supply voltage to be high enough to keep the switches on. In this situation, all the controllers **140** receive power from the charge pumps **130** so that they may operate at the higher voltage.

The circuits **199** also generate supply voltages using bias circuits **258**, **260** which may be 5V above a common ground. The bias circuits **258**, **260** supply power to the digital interface **126** and register memory **128**. In the embodiment of FIG. **5**, the first circuit **206** and the second circuit **208** are stacked to drive the string of LEDs **102**, so the output of the charge pump **252** equals the output of the bias **258**. Therefore, the output of the charge pump **252** and the output of the bias **258** can be connected together and share the load. Additionally, either the charge pump **252** or the bias **258** can be turned off if either can supply the required load by itself.

As briefly described above, the power system in the circuits **206**, **208** enable data transmissions between the circuits **206**, **208** even though they operate at different potentials when referenced to a ground. An example of the power and data connections between the first circuit **206** and the second circuit **208** is shown in FIG. **6**. In some embodiments, the voltage operating the first circuit **206** may be referenced to a ground node that is not at the same potential as the ground node of the second circuit **208**. In order for the communications to operate correctly given the different voltage potentials, the circuits **206**, **208** include level shifters **261**. As shown with reference to the second circuit **208**, the circuits **206**, **208** may each have a level shift up **262** and a level shift down **264**. The circuits **206**, **208** also include a plurality of buffers/drivers as described below. Data registers and other components are connected to the data lines, but are not shown in FIG. **6**.

Data is received on the line **110** by the second circuit **208**. The data line **110** connects to a driver **266**. The driver **266** operates from the voltage present in the second circuit **208**, which is five volts in this embodiment. The driver **266** outputs the data to the level shift up **262** in order for the data to operate at the five volt potential present in the first circuit **206**. The data may also be analyzed by the memory register **128**, FIG. **1**. The data is output from the level shift up **262** to a driver **268** that operates at the five volt potential present in the first circuit **206**. The driver **268** outputs the data on the line **114** to the first circuit **206**, which is substantially the same or identical to the second circuit **208**.

The data being transmitted from the first circuit **206** to the second circuit **208** has to be shifted down due to the higher potential present in the first circuit **206** relative to the second circuit **208**. A driver **270** transmits the data from the first circuit **206** to the line **116**. The data is received by a driver **272** in the second circuit **208**. Both the drivers **270**, **272** operate at the potential present in the first circuit **206**. The data is transmitted to the level shift down **264** where its potential is changed to operate at the voltage appropriate for the second circuit **208**. An output driver **274** outputs the data signal from the level shift down **264** to the line **112**.

If a circuit **100** is positioned at the top of the string of LEDs **200**, FIG. **4**, the data lines need to be connected together in order to allow the data to be transmitted to the other circuits. In the embodiment of FIG. **6**, the first circuit **206** controls the first portion of LEDs **220**, FIG. **4**, at the top of the string **218**. Therefore, data does not need to be transmitted further than the first circuit **206**, so the output **114** and the input **116** of the second circuit **206** are connected together. In the embodiment of FIG. **6**, an external line is used to connect the output **114** and the input **116**. It is noted that the output **114** and the input **116** may be connected internally by electronic switches that are not shown in FIG. **6**.

Referring again to FIGS. **3** and **4**, the current source **150** supplies current to a plurality of LEDs **102**. For example, each of the circuits **199** may control sixteen LEDs **102**. When the circuits **199** are connected in a series, the current source **150** provides current to many LEDs **102**. As the LEDs **102** turn off and on, the transients created by the off and on transitions need to be attenuated. With so many LEDs **102** connected to the current source **150**, several LEDs may be simultaneously turning off and on. The parasitic capacitance to ground found at the switching nodes will charge and discharge rapidly causing these transients.

Referring to FIG. **1**, in order to overcome the problems associated with the transients, the control signals for the LEDs **102** are analyzed so that the number of simultaneous on and off transitions is limited. Reference is made to FIG. **7**, which is a timing diagram showing an example of the PWM signals that may be received and processed by the circuit **100**, FIG. **1**. The data is received in the form of frames, wherein a first frame is received and processed. The circuit **100** displays data representative of the first frame while a second frame is received and processed. Accordingly, the displayed data is delayed. A blanking of all the LEDs **102** may occur between the frames. Each frame can be divided into many sub-frames based on the desired frame rate and the PWM resolution. Some of the sub-frames will be active and others may be disabled depending on the required light intensity.

The data received from the microprocessor is shown in the timing diagram **280**. The data may be in a serial format and stored in a frame buffer **281**. There are N number of PWM signals received into the frame buffer wherein each of the N PWM signals controls a single one of the LEDs **102**. For example PWM**1** controls the first LED in the string of LEDs **102** and PWM**2** controls the second LED in the string of LEDs **102**. In the embodiment wherein the circuit **100** controls sixteen LEDs **102**, there are sixteen PWM signals received into the frame buffer **281**.

As stated above, the PWM signals determine the amount of time that each of the LEDs **102** is on. In the embodiments of FIG. **7**, the high portion of the PWM signals represents the amount of time that one of the LEDs **102** is on. However, the high portion could also represent the amount of time that one of the LEDs **102** is off. It is noted that all the PWM signals may turn on at the same time, which may be after the blanking period. In other embodiments, the PWM signals may turn on during the frame period.

The PWM signals are sorted by a sorter **283** as shown in the diagram **282** so that each PWM signal is assigned a delay. The PWM signals are sorted so that the delays are ordered from the shortest PWM signal to the longest. With regard to the embodiment of FIG. **7**, PWM**2** has the shortest signal and is assigned delay one (D**1**). PWM**1** has the second shortest signal and is assigned delay two (D**2**) followed by PWM**3**, which is assigned delay three (D**3**). A reference signal PWMN is the last PWM signal and is assigned delay M, where M is an integer less or equal to N.

Now that the delays have been established, they are implemented by the delay **285** as shown by the timing diagram **284**. The delay may increment each of the PWM signals by a period of Td, which may be a few microseconds to a few milliseconds. The delay is based on the system response and is set so that there is enough of a delay for transients to dampen. The transient associated with PWM**2** will dampen before PWM**1** turns on. As shown, the signal PWM**2** is the shortest, so it is not delayed. PMW**1** is the second shortest, so it is delayed by the period Td. PWM**3** is the third shortest, so it is delayed by an amount of two times Td. As briefly described above, transients can be generated by having too many of the LEDs **102** turn off at the same time. By sorting the PWM signals from shortest to longest, the PWM signals will not turn off at the same time during a frame. In some embodiments, there is no delay applied when one LED turns on at the same time that a second LED turns off. The effects of the simultaneous on and off transitions cancel and no relevant transients are generated. In the case where there is no signal to display, for example when a sub-frame is not active, power savings can be implemented by disabling the current source **150** completely.

Having described some primary embodiments of the circuit **100**, other embodiments will now be described. Reference is made to FIG. **3**, which is the current source **150** that provides a current source for the LEDs **102**. As stated above, the LEDs **102** operate from a voltage that is typically much higher than the voltage required for the controller **192**. For example, the controller **192** may have digital and analog circuitry that operates at a few volts. The LEDs **102**, on the other hand, are typically driven by voltages ranging from ten to several hundred volts. The controller **192** may use a different supply than that provided for the LEDs **102**, which is expensive and may occupy a relatively large area on a circuit. The controller **192** could also convert the DC voltage used to supply the current for the LEDs **102**, but such DC to DC conversions are very inefficient.

A circuit **300** for efficiently converting the current supplying the LEDs **102** to a voltage for supplying the controller **192** is shown in FIG. **8**. A zener diode Z**1** is connected in series with the LEDs **102**. The zener diode Z**1** has a voltage that is equal to the operating voltage of the controller **192**, which is referred to as Vdd. The zener diode Z**1** converts the current flow through the LEDs **102** to the operating voltage. Two capacitors C**3** and C**4** are charged by switches SW**1**-SW**4**, which are controlled by a switching circuit **302**. The switching enables the voltage Vdd to be referenced to ground.

Another circuit **310** for efficiently converting the current supplied to the LEDs **102** to a voltage for supplying the controller **192** is shown in FIG. **9**. The circuit **310** is similar to the circuit **300**. However, the circuit **310** uses a switch SW**5** in place of the zener diode Z**1**. The switch SW**5** controls the charging time of the capacitor C**3**, which in turn controls the output voltage Vdd. It is noted that the switch SW**5** and the combination of SW**1** and SW**2** operate in opposite states so that one is off while the other is on. Therefore, current is always able to flow through the LEDs **102**.

Referring to the current source **150** of FIG. **3**, more efficiency can be achieved by stacking current regulators in series across the high input voltage. One problem with having series regulators is balancing the voltages across the regulators. A circuit **320** that balances the voltage across series regulators is shown in FIG. **10**. The circuit **320** includes a first current source **322** and a second current source **324**, wherein the first current source **322** is substantially similar to the current source **150** of FIG. **3**. The first current source **322** includes a first controller **326** and the second current source **324** includes a second controller **328**. Each current source **322**, **324** has switches or FETs **330** that are controlled by the controllers **326**, **328**.

The series connections of the regulators **322**, **324** enables voltage balancing between the regulators **322**, **324**, which enables the FETs **330** to have lower voltages across them. The first regulator **322** provides the current source for the LEDs **102**. The second current source **324** regulates the input voltage to the converters **322**, **324** in order to balance the voltages across the converters **322**, **324**.

While illustrative and presently preferred embodiments of the invention have been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed and that the appended claims are intended to be construed to include such variations except insofar as limited by the prior art.

What is claimed is:

1. A circuit for controlling a plurality of first LEDs connected in series, the circuit comprising:

a plurality of switches, wherein each switch is connectable between an anode and a cathode of one of the plurality of first LEDs, each of the switches having a first state wherein current does not pass through the switch and a second state wherein current passes through the switch;

a first data input for receiving data to program the switches;

a data line for transferring data between a circuit controlling second LEDs that are connected in parallel with the first LEDs and the circuit;

a data output for transferring data to other circuits controlling third LEDs that are connected in series with the first LEDs, wherein the data for controlling the switches is in pulse width modulation format and wherein the circuit further comprises a data sorter, wherein the data sorter sorts the pulse width modulated signals based on their on time; and

further comprising a charge pump, wherein the charge pump converts the voltage supplied to at least one of the first LEDs to the voltage required to operate the circuit for controlling the first LEDs, wherein a Zener diode is placed in series with the voltage supplied to at least one of the first LEDs, a voltage across the Zener diode being input to the charge pump to generate an operating voltage for the circuit for controlling the first LEDs.

2. The circuit of claim **1** and further comprising a level shift, wherein the level shift makes the voltage levels associated with the data compatible with the operating voltage of the circuit.

3. The circuit of claim **1**, wherein the charge pump has an output that is electrically connectable to the circuit that controls the third LEDs.

4. The circuit of claim **1** and further comprising a fault detector, wherein the fault detector determines if one of the first LEDs is functioning.

5. The circuit of claim **4**, wherein the fault detector transmits data when a fault is detected with one of the first LEDs.

6. The circuit of claim **4**, wherein the fault detector measures the voltage between the anode and cathode of one of the first LEDs.

7. The circuit of claim **4**, wherein the switch associated with a faulty one of the first LEDs is placed into the second state to cause current to bypass the faulty LED.

8. The circuit of claim **1** and further comprising a current source, wherein the current source drives the first LEDs, the current source comprising:

a voltage input having a first node and a second node;

an output node;

a first switch connected between the first node and the output node, wherein the first switch is controlled by a controller;

a second switch connected between the output node and the second node, wherein the second switch is controlled by the controller; and

an inductor connected between the output node and the LEDs.

9. The circuit of claim **8**, and further comprising a current sensor that senses the current through the inductor, wherein the current sensor has an output connected to the controller, and wherein the controller controls the first switch and the second switch based on the current sensed by the current sensor.

10. The circuit of claim **1** and further comprising a second data input that receives data from the circuit controlling the third LEDs.

11. The circuit of claim **10** wherein the data output is connectable to the second data input.

12. The circuit of claim **1** and further comprising a delay, wherein the switch with the shortest on time is turned on first.

13. The circuit of claim **1**, wherein the data is received in the format of a plurality of frames and wherein all of the switches are in the second state at the start of each frame.

14. The circuit of claim **13** and further comprising a current source that drives the LEDs and wherein the current source is disabled when all of the switches are in the second state.

15. The circuit of claim **1** wherein the charge pump charges a first capacitor during a first phase of a switching circuit and charges a second capacitor from the first capacitor during a second phase of the switching circuit in order to generate a voltage referenced to ground.

16. A device for controlling a plurality of LEDs, the device comprising:

a first circuit for controlling a first plurality of LEDs, the first circuit comprising:

a data line;

a plurality of switches, wherein each switch is connectable between the anode and cathode of one of the first plurality of LEDs, each of the switches having a first state wherein current does not pass through the switch and a second state wherein current passes through the switch, wherein data received on the data line controls the states of the switches;

a second circuit for controlling a second plurality of LEDs, wherein the first plurality of LEDs are connectable in series with the second plurality of LEDs, the second circuit comprising:

a first data line connectable to the data line of the first circuit;

a second data line connectable to a processor;

a plurality of switches, wherein each switch is connectable between the anode and cathode of one of the second plurality of LEDs, each of the switches having a first state wherein current does not pass through the switch and a second state wherein current passes through the switch, wherein data received on the second data line controls the states of the switches;

wherein data received by the second data line of the second circuit is analyzed to determine if the data is to control the switches in the first circuit, when the data is not to control the switches in the first circuit, the data is transmitted to the second circuit by way of the first data line; and

further comprising a charge pump, wherein the charge pump converts the voltage supplied to at least one of the first LEDs to the voltage required to operate the circuit for controlling the first LEDs, wherein a Zener diode is placed in series with the voltage supplied to at least one of the first LEDs, a voltage across the Zener diode being input to the charge pump to generate an operating voltage for the circuit for controlling the first LEDs.

17. The device of claim **16** and further comprising a third circuit for controlling a third plurality of LEDs, the third circuit comprising:

a data line connectable to the second data line of the second circuit;

a plurality of switches, wherein each switch is connectable between the anode and cathode of one of the third plurality of LEDs, each of the switches having a first state wherein current does not pass through the switch and a second state wherein current passes through the switch, wherein data received on the data line controls the states of the switches;

wherein data received by the data line controls the switches in the third circuit.

18. The device of claim **16** and further comprising a current source, wherein the current source drives the first plurality of LEDs and the second plurality of LEDs, the current source comprising:

a voltage input having a first node and a second node;

an output node;

a first switch connected between the first node and the output node, wherein the first switch is controlled by a controller;

a second switch connected between the output node and the second node, wherein the second switch is controlled by the controller; and

an inductor connected to the output node and connectable to the second plurality of LEDs.

19. A circuit for controlling a plurality of first LEDs connected in series, the circuit comprising:

a plurality of switches, wherein each switch is connectable between the anode and cathode of one of the plurality of first LEDs, each of the switches having a first state wherein current does not pass through the switch and a second state wherein current passes through the switch;

a first data input for receiving data to program the switches, wherein the switches are controlled by pulse width modulated signals;

a data line for transferring data between a circuit controlling second LEDs that are connected in parallel with the first LEDs and the circuit;

a data output for transferring data to other circuits controlling third LEDs that are connected in series with the first LEDs;

a data sorter, wherein the data sorter sorts the pulse width modulated signals based on their on time;

a delay, wherein the switch with the shortest on time is turned on first;

a current source comprising:

a voltage input having a first node and a second node;

an output node;

a first switch connected between the first node and the output node, wherein the first switch is controlled by a controller;

a second switch connected between the output node and the second node, wherein the second switch is controlled by the controller; and

an inductor connected to the output node and connectable to the second plurality of LEDs; and

further comprising a charge pump, wherein the charge pump converts the voltage supplied to at least one of the first LEDs to the voltage required to operate the circuit for controlling the first LEDs, wherein a Zener diode is placed in series with the voltage supplied to at least one of the first LEDs, a voltage across the Zener diode being input to the charge pump to generate an operating voltage for the circuit for controlling the first LEDs.

20. A circuit for controlling a plurality of first LEDs connected in series, the circuit comprising:

a plurality of switches, wherein each switch is connectable between an anode and a cathode of one of the plurality of first LEDs, each of the switches having a first state wherein current does not pass through the switch and a second state wherein current passes through the switch;

a first data input for receiving data to program the switches;

a data line for transferring data between a circuit controlling second LEDs that are connected in parallel with the first LEDs and the circuit; and

a data output for transferring data to other circuits controlling third LEDs that are connected in series with the first LEDs;

further comprising a control circuit for driving each one of the switches independently with PWM signals to individually dim the LEDs; and

further comprising a charge pump, wherein the charge pump converts the voltage supplied to at least one of the first LEDs to the voltage required to operate the circuit for controlling the first LEDs, wherein a switch is placed in series with the voltage supplied to at least one of the first LEDs, a voltage across the switch being input to the charge pump to generate an operating voltage for the circuit for controlling the first LEDs.

21. A circuit for controlling a plurality of first LEDs connected in series, the circuit comprising:

a plurality of switches, wherein each switch is connectable between an anode and a cathode of one of the plurality of first LEDs, each of the switches having a first state wherein current does not pass through the switch and a second state wherein current passes through the switch;

a first data input for receiving data to program the switches;

a data line for transferring data between a circuit controlling second LEDs that are connected in parallel with the first LEDs and the circuit;

a data output for transferring data to other circuits controlling third LEDs that are connected in series with the first LEDs, wherein the data for controlling the switches is in pulse width modulation format and wherein the circuit further comprises a data sorter, wherein the data sorter sorts the pulse width modulated signals based on their on time; and

further comprising a charge pump, wherein the charge pump converts the voltage supplied to at least one of the first LEDs to the voltage required to operate the circuit for controlling the first LEDs, wherein a switch is placed in series with the voltage supplied to at least one of the first LEDs, a voltage across the switch being input to the charge pump to generate an operating voltage for the circuit for controlling the first LEDs.

22. The circuit of claim **21** wherein the charge pump charges a first capacitor during a first phase of a switching circuit and charges a second capacitor from the first capacitor during a second phase of the switching circuit in order to generate a voltage referenced to ground.

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